Studies for Students.

STRATIFIED DRIFT.

CONTENTS.

Its abundance.—The notion is widespread that the drift deposits of the glacial period are unstratified. Lack of stratification, indeed, is the characteristic which, above all others, is popularly supposed to be the special mark of the formations to which the ice gave rise.

While it is true that glacier ice does not distinctly stratify the deposits which it makes, it is still true that a very large part of the drift for which the ice of the glacial period was directly or

indirectly responsible is stratified. That this should be so is not strange when it is remembered that most of the ice was ultimately converted into running water, just as the glaciers of today are. The relatively small portion which disappeared by evaporation was probably more than counterbalanced, at least near the margin of the ice, by the rain which fell upon it. It cannot be considered an exaggeration, therefore, to say that the total amount of water which operated upon the drift, first and last, was hardly less than the total amount of the ice itself. The drift deposited by the marginal part of the ice was affected during its deposition, not only by the water which arose from the melting of the ice which did the depositing, but by much water which arose from the melting of the ice far back from the margin. The general mobility of the water, as contrasted with ice, allowed it to concentrate its activities along those lines which favored its motion, so that different portions of the drift were not affected equally by the water of the melting ice.

All in all it will be seen that the water must have been a very important factor in the deposition of the drift, especially near the margin of the ice. But the ice-sheet had a marginal belt throughout its whole history, and water must have been active and effective along this belt, not only during the decadence of the ice-sheet, but during its growth as well. It is further to be noted that any region of drift stood good chance of being operated upon by the water after the ice had departed from it, so that in regions over which topography directed drainage after the withdrawal of the ice, the water had the last chance at the drift, and modified it in such a way and to such an extent as circumstances permitted.

Its origin.—There are various ways in which stratified drift may arise in connection with glacier deposits. It may come into existence by the operation of water alone; or by the coöperation of ice and water. Where water alone was immediately responsible for the deposition of stratified drift, the water concerned may have owed its origin to the melting ice, or it may have existed independently of the ice in the form of lakes or

seas. When the source of the water was the melting ice, the water may have been running, when it was actively concerned in the deposition of stratified drift, or it may have been standing (glacial lakes and ponds) when it was passively concerned. When ice coöperated with water in the development of stratified drift the ice was generally a passive partner.

GLACIAL DRAINAGE.

The body of an ice-sheet during any glacial period is probably melting more or less at some horizons all the time and at all horizons some of the time. Most of the water which is produced at the surface during the summer sinks beneath it. Some of it may congeal before it sinks far, but much of it reaches the bottom of the ice without refreezing. It is probable that melting is much more nearly continuous in the body of a moving ice-sheet than at its surface, and that some of the water thus produced sinks to the bottom of the ice without refreezing. At the base of the ice, so long as it is in movement, there is doubtless more or less melting, due both to friction and to the heat received by conduction from the earth below. Thus in the ice and under the ice there must have been more or less water in motion throughout essentially all the history of an ice-sheet.

If it be safe to base conclusions on the phenomena of existing glaciers, it may be assumed that the waters beneath the ice, and to a less extent the waters in the ice, organized themselves to a greater or less degree into streams. For longer or shorter distances these streams flowed in the ice or beneath it. Ultimately they escaped from its edge. The subglacial streams doubtless flowed, in part, in the valleys which affected the land surface beneath the ice, but they were probably not all in such positions.

The courses of well-defined subglacial streams were tunnels. The bases of the tunnels were of rock or drift, while the sides and tops were of ice. It will be seen, therefore, that their courses need not have corresponded with the courses of the valleys beneath the ice. They may sometimes have followed lines

more or less independent of topography, much as water may be forced over elevations in closed tubes. It is not to be inferred, however, that the subglacial streams were altogether independent of the sub-ice topography. The tunnels in which the water ran probably had too many leaks to allow the water to be forced up over great elevations. This, at least, must have been the case where the ice was thin or affected by crevasses. Under such circumstances the topography of the land surface must have been the controlling element in determining the course of the subglacial drainage.

When the streams issued from beneath the ice the conditions of flow were more or less radically changed, and from their point of issue they followed the usual laws governing river flow. If the streams entered static water as they issued from the ice, and this was true where the ice edge reached the sea or a lake, the static water modified the results which the flowing waters would otherwise have produced.

STAGES IN THE HISTORY OF AN ICE-SHEET.

The history of an ice-sheet which no longer exists involves at least two distinct stages. These are (1) the period of growth, and (2) the period of decadence. If the latter does not begin as soon as the former is complete, an intervening stage, representing the period of maximum ice extension, must be recognized. In the case of the ice-sheets of the glacial period, each of these stages was probably more or less complex. The general period of growth of each ice-sheet is believed to have been marked by temporary, but by more or less extensive intervals of decadence, while during the general period of decadence, it is probable that the ice was subject to temporary, but to more or less extensive intervals of recrudescence. For the sake of simplicity, the effects of these oscillations of the edge of the ice will be neglected at the outset, and the work of the water accompanying the two or three principal stages of an ice-sheet's history will be studied

as if interruptions in the advance and in the retreat, respectively, had not occurred.

As they now exist, the deposits of stratified drift made at the edge of the ice or beyond it during the period of its maximum extension present the simplest and at the same time most sharply defined phenomena, and are therefore considered first.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE MAXIMUM EXTENSION OF THE ICE.

The deposits made by the water at the time of the maximum extension of the ice and during its final retreat, were never disturbed by subsequent glacier action. So far as not destroyed by subsequent erosion, they still retain the form and structure which they had at the outset. Such drift deposits, because they lie at the surface, and because they are more or less distinct topographically as well as structurally, are better known than the stratified drift of other stages of an ice-sheet's history.

Of stratified drift made during the maximum extension of the ice, and during its final retreat, there are several types. Some of them have been adequately described and defined in the literature of glacial geology, and would need no more than passing reference in this connection, were it not that, under certain conditions, they lose their distinctive characteristics, without being altogether destroyed. Their recognition then becomes a matter of difficulty, and their real relations are likely to be misunderstood, when the phenomena are in reality rather simple.

A. At the edge of ice, on land.—If the subglacial streams flowed under "head," the pressure was relieved when they escaped from the ice. With this relief, there was diminution of velocity. With the diminution of velocity, deposition of load would be likely to take place. Since these changes would be likely to occur at the immediate edge of the ice, one class of stratified drift deposits would be made in this position, in immediate contact with the edge of the ice, and their form would be influenced by it. At the stationary margin of an ice-sheet, there-

fore, at the time of its maximum advance, ice and water must have coöperated to bring into existence considerable quantities of stratified drift.

The edge of the ice was probably ragged, as the ends of glaciers are today, and as the waters issued from beneath it, they must frequently have left considerable quantities of such débris as they were carrying, against its irregular margin, and in its reëntrant angles and marginal crevasses. When the ice against which this débris was first lodged melted, the marginal accumulations of gravel and sand often assumed the form of *kames*, a type of stratified drift which is well known.[1] A typical kame is a hill, hillock, or less commonly a short ridge of stratified drift; but several or many are often associated, giving rise to groups and areas of kames. Kames are often associated with terminal moraines, a relation which emphasizes the fact of their marginal origin.

So far as the superficial streams which flowed to the edge of the ice carried débris, this was subject to deposition as the streams descended from the ice. Such drift would tend to increase the body of marginal stratified drift from subglacial sources.

Marginal accumulations of stratified drift, made by the coöperation of running water and ice, must have had their most extensive development, other things being equal, where the margin of the ice was longest in one position, and where the streams were heavily loaded. The deposits made by water at the edge of the ice differ from those of the next class — made beyond the edge of the ice — in that they were influenced in their disposition and present topography, by the presence of ice.

[1] Until recently kames have not been discriminated from eskers, and in the older literature the two are confused. Kames, as distinct from eskers, are defined and discussed in the following places, though the list is incomplete:

CHAMBERLIN, 3d Ann. Rep. U. S. Geol. Surv., p. 300; Am. Jour. Sci., Vol. XXVII, p. 378; Compte-Rendu, 5th Session International Congress of Geologists, p. 187; JOURNAL OF GEOLOGY, Vol. I, p. 255; JOURNAL OF GEOLOGY, Vol. II, p. 531. GEIKIE, "Great Ice Age," 3d Edition, chap. xv. SALISBURY, Report of the State Geologist of New Jersey for 1891, pp. 89–95; Ibid., 1892, pp. 41, 79.

B. Beyond the edge of the ice, on land.—As the waters escaping from the ice flowed farther, deposits of stratified drift were made quite beyond the edge of the ice. The forms assumed by such deposits are various, and depended on various conditions. Where the waters issuing from the edge of the ice found themselves concentrated in valleys, and where they possessed sufficient load, and not too great velocity, they aggraded the valleys through which they flowed, developing fluvial plains of gravel and sand, which often extended far beyond the ice. Such fluvial plains of gravel and sand constitute the *valley trains*[1] which extend beyond the unstratified glacial drift in many of the valleys of the United States. They are found especially in the valleys leading out from the stouter terminal moraines of later glacial age. From these moraines, the more extensive valley trains take their origin, thus emphasizing the fact that they are deposits made by water beyond a stationary ice margin. Valley trains have all the characteristics of alluvial plains built by rapid waters carrying heavy loads of detritus. Now and then their surfaces present slight variations from planeness, but they are minor. Like all plains of similar origin they decline gradually, and with diminishing gradient, down stream. They are of coarser material near their sources, and of finer below. Such stratified drift, which constitutes a distinct topographic, as well as genetic type, is well known, and further description or discussion is unnecessary.

Where the subglacial streams did not course through subglacial valleys, they did not always find valleys at hand upon their issuance from the ice. Under such circumstances, each heavily loaded stream coming out from beneath the ice must have tended to develop a plain of stratified material near its point of issue—a sort of alluvial fan. Where several such streams came out from beneath the ice near each other for a considerable period of time, their several plains, or fans, were

[1] For fuller definition and illustration of valley trains see CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 302; JOURNAL OF GEOLOGY, Vol. I, p. 534. SALISBURY, Report of the State Geologist of New Jersey, 1892, pp. 102–105.

likely to become continuous by lateral growth. Such border plains of stratified drift differ from valley trains particularly (1) in being much less elongate in the direction of the drainage; (2) in being much more elongate parallel to the margin of the ice; and (3) in not being confined to valleys. Such plains stood an especially good chance of development where the edge of the ice remained constant for a considerable period of time, for it was under such conditions that the issuing waters had opportunity to do much work.

Thus arose the type of stratified drift variously known as *overwash plains*, *morainic plains*, and *morainic aprons*. These overwash plains are sometimes found with a width of several miles. Like the valley trains, they are topographically and genetically distinct, and their relations are well known. They have been abundantly described in the literature of glacial geology, and it is, therefore, not needful that more be said concerning them at this point.[1]

Overwash plains may sometimes depart from planeness by taking on some measure of undulation, of the sag and swell (kame) type, especially near their iceward edges. The same is often true of the heads of valley trains. The heads of valley trains and the inner edges of overwash plains, it is to be noted, occupy the general position in which kames are likely to be formed, and the undulations which often affect these parts of the trains and plains, respectively, are probably to be attributed to the influence of the ice itself. Valley trains and overwash plains, therefore, at their upper ends and edges respectively, may take on some of the features of kames. Indeed, either may head in a kame area.[2]

Occasionally a morainic apron, or stratified drift in the general position of a moraine apron, is affected by numerous sags without corresponding elevations. This topographic type has

[1] This type is described in the following places, among many others:

CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 303; JOURNAL OF GEOLOGY, Vol. II, p. 533. SALISBURY, Ann. Report of the State Geologist of New Jersey, 1892. p. 97.

[2] SALISBURY, Ann. Report of State Geologist of New Jersey, 1892, p. 94.

received the name of *pitted plain*. The sags, in many cases at least, appear to be intimately connected with the ice edge, and so to be marginal phenomena.

Not only may morainic plains and valley trains grade into kame areas at their heads, but they may grade into each other. A wide valley train and a narrow overwash plain may closely simulate each other, and in individual cases it is not easy to say whether the deposits are more properly referred to the one or the other of the two classes.[1] This is especially true where an overwash plain is developed in a valley.

At many points near the edge of the ice during its maximum stage of advance, there probably issued small quantities of water not in the form of well-defined streams, bearing small quantities of detritus. These small quantities of water, with their correspondingly small loads, were unable to develop considerable plains of stratified drift, but produced small patches instead. Such patches have received no special designation.

When the waters issuing from the edge of the ice were sluggish, whether they were in valleys or not, the materials which they carried and deposited were fine instead of coarse, giving rise to deposits of silt, or clay, instead of sand or gravel.

In the deposition of stratified drift beyond the edge of the ice, the latter was concerned only in so far as its activity helped to supply the water with the necessary materials.

C. Deposits at and beyond the edge of the ice in standing water.— The waters which issued from the edge of the ice sometimes met a different fate. The ice in its advance often moved up river valleys. When at the time of its maximum extension, it filled the lower part of a valley, leaving the upper part free, drainage through the valley stood good chance of being blocked. Where this happened a marginal valley lake was formed. Whenever the ice spread over a land surface sloping toward it, there was the possibility of the development of a lake basin between the ice on one hand, and the land surface on the other. Marginal lakes and ponds arising in these and other

[1] SALISBURY, Annual Report of the State Geologist of New Jersey, 1891, p. 97.

ways, were probably not rare at the time of the maximum extension of the ice, and more or less drainage from the ice must have found its way into them. Wherever this occurred, stratified deposits of drift were made in the lakes, the materials for which were borne into the standing water by the streams which issued from the ice. *Deltas* must have been formed where well-defined streams entered the lakes, and *subaqueous overwash plains*[1] where deltas became continuous by lateral growth. The accumulation of stratified drift along the ice-ward shores of such lakes must have been rapid, because of the abundant supply of detritus. These materials were probably shifted about more or less by waves and shore currents, and some of them may have been widely distributed. Out from the borders of such lakes, fine silts and clays must have been in process of deposition, at the same time that the coarse materials were being laid down nearer shore.

Deposition must have taken place in a similar way along the shores of the sea wherever the ice reached it. The silt, sand, gravel, etc., carried to the sea by running water was either deposited at once, or worked over and transported greater or less distances by waves and littoral currents. Such deposits still remain beneath the sea, unless changes of level have brought them above the surface.

During the maximum extension of an ice-sheet, therefore, there was chance for the development, at its edge or in advance of it, of the following types of stratified drift: (1) kames and kame belts, at the edge of the ice; (2) fluvial plains or valley trains, in virtual contact with the ice at their heads; (3) border plains or overwash plains, in virtual contact with the ice at their upper edges; (4) ill-defined patches of stratified drift, coarse or fine, near the ice; (5) subaqueous overwash plains and deltas, formed either in the sea or lakes at or near the edge of the ice; (6) lacustrine and marine deposits of other sorts, the materials for which were furnished by the waters arising from the ice.

[1] Annual Report of the State Geologist of New Jersey for 1892, p. 99; *ibid.*, 1893, p. 266.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE RETREAT OF THE ICE.

During the retreat of any ice-sheet, disregarding oscillations of its edge, its margin withdrew step by step from the position of extreme advance to its center. When the process of dissolution was complete, each portion of the territory once covered by the ice, had at some stage in the dissolution, found itself in a marginal position. At all stages in its retreat the waters issuing from the edge of the ice were working in the manner already outlined in the preceding paragraphs. Two points of difference only need to be especially noted. In the first place the deposits made by waters issuing from the retreating ice, were laid down on territory which the ice had occupied, and their subjacent stratum was often glacial drift. So far as this was the case, the stratified drift was supermorainic, not extra-morainic. In the second place the edge of the ice in retreat did not give rise to such sharply marked formations as the edge of the ice which was stationary. The processes which had given rise to valley trains, overwash plains, kames, etc., while the ice edge was stationary, were still in operation, but the line or zone of activity (the edge of the ice) was continually retreating, so that the foregoing types, more or less dependent on a stationary edge, were rarely well developed. As the ice withrew, therefore, it allowed to be spread over the surface it had earlier occupied, many incipient valley trains, overwash plains, and kames, and a multitude of ill-defined patches of stratified drift, thick and thin, coarse and fine. Wherever the ice halted in its retreat these various types stood chance of better development.

Such deposits would not cover all the surface discovered by the ice in its retreat, since the issuing waters, thanks to their great mobility, concentrated their activities along those lines which favored their motion. Nevertheless the aggregate area of the deposits made by water outside the ice as it retreated, was great.

It is to be noted that it was not streams alone which were operative as the ice retreated. As its edge withdrew, lakes and

ponds were continually being drained, as their outlets, hitherto choked by the ice, were opened, while others were coming into existence as the depressions in the surface just freed from ice, filled with water. Lacustrine deposits at the edge of the ice during its retreat were in all essential respects identical with those made in similar situations during its maximum extension.

Disregarding oscillations of the ice edge at these stages, the deposits made by extraglacial waters during the maximum extension of an ice-sheet, and during its retreat, were always left at the surface, so far as the work of that ice-sheet was concerned. The stratified drift laid down by extraglacial waters in these stages of the last ice-sheet which affected any region of our continent still remain at the surface in much the condition in which they were deposited, except for the erosion they have since suffered. It is because of their position at the surface that the deposits referable to these stages of the last ice-sheet of any given region have received most attention and are therefore most familiar.

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE ADVANCE OF THE ICE.

During the advance of an ice-sheet, if its edge forged steadily forward, the waters issuing from it, and flowing beyond, were effecting similar results. They were starting valley trains, overwash plains, kames, and small ill-defined patches of stratified drift which the ice did not allow them to complete, before pushing over them, and shoving forward the zone of activity of extraglacial waters. Unlike the deposits made by the waters of the retreating ice, those made by the waters of the advancing ice were laid down on territory which had not been glaciated, or at least not by the ice-sheet concerned in their deposition. If the ice halted in its advance, there was at such time and place opportunity for the better development of extraglacial stratified drift.

Lakes as well as streams were concerned in the making of stratified beds of drift, during the advance of the ice. Mar-

ginal lakes were extinguished by having their basins filled with the advancing ice, which displaced the water. But new ones were formed, on the whole, as rapidly as their predecessors became extinct, so that lacustrine deposits were making at intervals along the margin of the advancing ice.

Deposits made in advance of a growing ice-sheet, by waters issuing from it, were subsequently overridden by the ice, to the limit of its advance, and in the process, suffered destruction, modification, or burial, in whole or in part, so that now they rarely appear at the surface.

DEPOSITS MADE BY SUBGLACIAL STREAMS.

Before their issuance from beneath the ice, subglacial waters were not idle. Their activity was sometimes erosive, and at such times stratified deposits were not made. But where the subglacial streams found themselves overloaded, as seems frequently to have been the case, they made deposits along their lines of flow. Where such waters were not confined to definite channels, their deposits probably took on the form of irregular patches of silt, sand, or gravel; but where depositing streams were confined to definite channels, their deposits were correspondingly concentrated. When subglacial streams were confined to definite channels, the same may have been constant in position, or may have shifted more or less from side to side. Where the latter happened there was a tendency to the development of a belt or strip of stratified drift having a width equal to the extent of the lateral migrations of the under-ice stream. Where the channel of the subglacial stream remained fixed in position, the deposition was more concentrated, and the bed was built up. If the stream held its course for a long period of time, the measure of building may have been considerable. In so far as these channel deposits were made near the edge of the ice, during the time of its maximum extension or retreat they were likely to remain undisturbed during its melting. The aggraded channels then came to stand out as ridges. These ridges of gravel and sand are known as *osars* or *eskers*. It is not to be inferred that

eskers never originated in other ways, but it seems clear that this is one method, and perhaps the principal one, by which they came into existence. Eskers early attracted attention, partly because they are relatively rare, and partly because they are often rather striking topographic features. Their characteristics are well known and will not be recounted here.[1] The essential conditions, therefore, for their formation, so far as they are the product of subglacial drainage, are (1) the confining of the subglacial streams to definite channels, and (2) a sufficient supply of detritus.

Subglacial deposits of stratified drift were sometimes made on unstratified drift (till) already deposited by the ice before the location of the stream, and sometimes on the rock surfaces on which no covering of glacier drift had been spread.

It is to be kept in mind that subglacial drainage was operative during the advance of an ice-sheet, during its maximum extension, and during its retreat, and that during all these stages it was effecting its appropriate results. It will be readily seen, however, that all deposits made by subglacial waters, were subject to modification or destruction or burial, through the agency of the ice, and that those made during the advance of the ice were less likely to escape, than those made during its maximum extension or retreat.

DEPOSITS OF SUPERGLACIAL AND ENGLACIAL STREAMS.

Superglacial and englacial streams might be supposed to make deposits in their channels. It has even been conceived that this

[1] Eskers or osars are described and discussed in the following places, often under the name of kames or serpentine kames: CHAMBERLIN, 3d Ann. Report U. S. Geol. Surv., p. 299; Compte-Rendu, 5th Session of the International Congress of Geologists; JOURNAL OF GEOLOGY, Vol. I, p. 255; *Ibid.*, Vol. II, p. 529. STONE, Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 430–69. UPHAM, Geol. of N. Hampshire, Vol. III, (under kames); Proc. A. A. A. S., Vol. XXV, p. 216; Report Minn. Geol. Survey, Vol. I, p. 545; Am. Jour. Sci., Vol. CXIV (1877), p. 459, SHALER, Proc. Bost. Soc. Nat. Hist., Vol. XXIII, p. 36; 7th Ann. Report U. S. Geol. Surv., p. 314; 9th Ann. Report U. S. Geol. Surv., p. 549. DAVIS, Proc. Bost. Soc. Nat. Hist., Vol. XXV, p. 477–492. GEIKIE, Great Ice Age, 3d edition, Chap. XIV. HOLST, Am. Nat., Vol. XXII, pp. 590–711. SALISBURY, Ann. Rep. State Geologist of New Jersey, 1892, pp. 41, 79.

was the principal mode of origin of eskers. Against this view, and against the view that superglacial stream deposits are of consequence quantitatively, stand two facts. (1) So far as known the surfaces of ice-sheets are free from drift (apart from wind-blown dust) except for a fraction (and generally a small one) of a mile from their edges; and (2) superglacial streams are in general much too swift to deposit drift, or to allow it to accumulate in their channels. The channels of most superglacial streams in North Greenland, *even near the edge of the ice where surface débris is abundant*, are absolutely free from drift. Judging from the force with which they issue from the ice, englacial streams are likewise much too swift to allow of deposition along their channels, as a general rule.

Such trivial accumulations of drift as may be made in superglacial or englacial channels would ultimately reach the land surface. During the advance of the ice they would be delivered onto the land, as the ice which sustained them moved forward into the zone of melting. They would then be overridden by its further forward motion. During the retreat of the ice, such deposits, once they reached the land surface, would not be subsequently destroyed or overridden by it.

Summary.—Such are the main phases of water action in connection with a single ice-sheet, on the assumption that the edge of the same did not oscillate backward and forward during the period of its advance or retreat. Were this the complete history of an ice-sheet, the stratified deposits, as they now exist, would be (1) in part extraglacial—those made by waters beyond the extreme advance of the ice; (2) in part supermorainic (supertill)—especially those made by extraglacial waters during the retreat of the ice; and (3) in part submorainic (sub-till)—chiefly those made by extraglacial waters during the advance of the ice, and subsequently buried. The actual relations of the stratified drift to the unstratified are, however, far less simple.

RELATION OF STRATIFIED TO UNSTRATIFIED DRIFT.

Deposits made by extraglacial waters during the advance of the ice, edge not oscillating.—At all stages of the glacial period,

extraglacial streams were depositing gravel, sand, or silt in the valleys through which they flowed. Wherever the ice halted temporarily in its advance, valley trains of greater or less extent may have been developed. All those valley deposits which were made during the first advance of the ice were made on territory which was free from glacial drift. Subsequently the glacier ice overrode them in whole or in part, often burying them beneath its own moraine deposits (till). So too, during the first advance of the ice, the waters which did not concentrate themselves in valleys as they issued from the edge of the ice, made deposits in the form or in the position of overwash plains of gravel, sand, or silt. Well developed overwash plains may have been built up before the ice reached its maximum extension, wherever the ice edge stood for a sufficiently long interval of time in a favorable topographic position. Such overwash plains as were developed during the first advance of the ice, lay upon territory which the ice had never invaded, and constitute, if they still remain, the lowest member of the drift series. Subsequently, in its further advance, the ice overrode these deposits sometimes destroying them and sometimes burying them beneath deposits strictly glacial.

It was not simply by extraglacial streams that stratified drift was deposited during the advance of the ice. The marginal lakes which came into existence during the advance of the ice, and there were many, likewise gave rise to stratified deposits of glacio-lacustrine origin. So far as these were formed upon territory which was free from drift, and subsequently overridden by the ice, they were likely to be buried so far as not destroyed. Deposits formed in the margins of seas at the edge of the ice would be subject to the same changes as those formed in lakes, in so far as they were subsequently overridden by the ice.

Still supposing the edge of the ice not to have oscillated, all the deposits of extraglacial waters made during its first advance, whether of the valley-train, overwash plain, lacustrine or other types, were liable to destruction by the further progress of the ice. So far as they were not destroyed they were liable to bur-

ial beneath unstratified drift deposited by the ice itself. So far as not destroyed, therefore, the exisiting deposits of stratified drift made during the first advance of the ice are likely to occupy the basal position (submorainic) in the drift series, in all the territory subsequently overspread by the ice.

Effect of edge oscillation. — Hitherto the assumptions have been made, for the sake of simplicity, that the advancing edge of the ice forged steadily forward, and that the retreating edge was subject to no temporary advances. It is probable that neither of these assumptions is true. It is believed rather that the advance of the ice was interrupted by many minor oscillations of its edge, both seasonal and periodic, though the sum of the advances was greater than the sum of the retreats during any given epoch, up to the time when the ice reached its greatest extension. When the ice advanced to a certain line, and then receded temporarily, incipient overwash plains, or valley trains, or lacustrine beds, or ill-defined patches of gravel and sand, were doubtless deposited on the territory from which the ice had temporarily receded. The gravel and sand in this case would in general lie, not on a driftless bed, but over deposits made by the ice before its temporary recession. The subsequent advance of the ice would be likely to bury these deposits of stratified drift so far as it did not destroy them. Thus by oscillations of the edge of the ice during the general period of its advance, stratified sand and gravel may have come to be enclosed between beds of till. The extent of the area where this sort of action might take place at any one time would depend upon the amount of oscillation which the ice underwent during its advance. But it may have taken place at many times and places and at many stages in the development of an ice-sheet, so that the interbedding of the two types of drift by this process may have been considerable, in the aggregate, during the advance of the ice.

Deposits made by extraglacial waters during the retreat of the ice. —Stratified deposits made by extraglacial streams during the retreat of the ice of any epoch would remain at the surface

(supermorainic) so far as the ice of that epoch was concerned, except in so far as forward oscillatory movements intervened in the general period of retreat. So far as such movements intervened, their tendency would be to bury or destroy such stratified deposits as were overridden by the temporary advances of the ice, making them intermorainic (inter-till). In a complex body of drift deposited by a single ice-sheet, the edge of which was subject to oscillation, it would not always be possible to tell which beds of intermorainic stratified drift were deposited during the advance of the ice and which during the retreat, though the latter would of course overlie the former.

Deposits made by streams as they issued from the ice.—When streams issued from beneath the ice they often made very considerable deposits at the point of issue (kames, alluvial fans, etc.). In case of simple (without oscillation) advance or retreat of the ice, deposits of this sort made during the maximum extension of the ice and during its retreat would remain undestroyed and unburied so far as ice of that epoch is concerned. Those made by the ice at the time of its maximum extension might rest on a driftless surface or on extraglacial stratified drift deposited in advance of the ice, while those made during its retreat would be likely to lie on till.

The deposits made in this position during the first advance of the ice over any region, were likewise liable to rest on driftless surfaces or on stratified drift deposited in advance of the ice itself. The advance of the ice was likely to destroy them in whole or in part, and bury what escaped destruction. Stratified deposits made at the margin of an advancing ice-sheet the edge of which was not oscillating are therefore likely to occupy a submorainic position, to the limit of ice advance.

In case the edge of the ice oscillated during its advance, the kame deposits made during a recessional phase of an oscillation might rest on the till of the preceding advance phase. Likewise the stratified deposits at the edge of the ice during its retreat, commonly, but not universally, rested on till. Marginal deposits of stratified drift made during a recessional phase

of an oscillating movement during the general retreat, were liable to destruction or burial by the next advance phase. So far as buried, they commonly assumed an inter-till position. Those made during the general recession were of course more liable to escape destruction than those made during the advance.

Deposits made by subglacial streams.—Subglacial streams, as well as extraglacial, made more or less extensive deposits of stratified drift. These were sometimes concentrated along sharply limited channels (eskers), and sometimes more widely spread. They were sometimes made on the rock surface below all drift, but more commonly on unstratified drift (till) which the ice had already deposited. Because of the ever-changing conditions at the bottom of moving ice, it is probable that the ice frequently came to occupy beds which streams had temporarily commanded. Wherever this happened, the stratified deposits were likely to be destroyed in whole or in part, or buried. In the latter case they became intermorainic, if they rested upon till, or submorainic, if on rock. It is believed that very large numbers of beds of stratified drift, of limited extent, became in this way interbedded with till. Subglacial waters which did not organize themselves into regular systems of drainage, must have done a similar work on a smaller scale.

Deposits made beneath the ice during its maximum extension in any epoch, and especially near its edge, stood less chance of being buried by later glacial deposits. Stratified deposits made beneath the ice during its retreat, and especially those made near its edge at any stage, were still less likely to attain an inter-till position.

Deposits made by superglacial and englacial streams.—Theoretically, superglacial streams likewise may have made deposits of stratified drift on the ice or in ice valleys. Practically such deposits were probably not made except near the edge of the ice, for nowhere else was there superglacial drift. Even here they were probably not important. Such accumulations of this sort as were made during the final recession of the ice-sheet were delivered on the land as the ice melted, and should remain

at the surface to the present time, so far as the ice of that epoch was concerned. Such deposits as were made by superglacial streams during the advance of the ice must likewise have been delivered on the land surface, but would have been subsequently destroyed or buried, becoming in the latter case, submorainic. This would be likely to be the fate of all such superglacial gravels as reached the edge of the ice up to the time of its maximum advance.

Streams descending from the surface of the ice into crevasses also must have carried down sand and gravel where such materials existed on the ice. These deposits may have been made on the rock which underlies the drift, or they may have been made on stratified or unstratified drift already deposited. In either case they were liable to be covered by till, thus reaching an inter-till or sub-till position.

Englacial streams probably do little depositing, but it is altogether conceivable that they might accumulate such trivial pockets of sand and gravel as are found not infrequently in the midst of till. The inter-till position would be the result of subsequent burial after the stratified material reached a resting place.

Complexity of relations.— From the foregoing it becomes clear that there are diverse ways by which stratified drift, arising in connection with an ice-sheet, may come to be interbedded with till, when due recognition is made of all the halts and oscillations to which the edge of a continental glacier may have been subject during both its advance and retreat.

It is evident that the stratified drift and the unstratified drift had abundant opportunity to be associated in all relationships and in all degrees of intimacy. It is evident that stratified drift may alternate with unstratified many times in a formation of drift deposited during a single ice epoch. The extent of individual beds of stratified drift, either beneath the till or interbedded with it, may not be great, though their aggregate area and their aggregate volume is very considerable. It is to be borne in mind that the ice, in many places, doubtless destroyed

all the stratified drift deposited in advance on the territory which it occupied later, and that in others it may have left only patches of once extensive sheets. This may help to explain why it so frequently happens that a section of drift at one point shows many layers of stratified drift, while another section close by, of equal depth, and in similar relationships, shows no stratified material whatsoever. It also makes it clear that the interrelations of the two types of drift are, on the whole, less complex than they might have been had all the deposits once made by the ice and its accompanying waters escaped destruction.

After what has been said, it is hardly necessary to add that two beds of till, separated by a bed of stratified drift, do not necessarily represent two distinct glacial epochs.

In any region, which has been affected successively by two or more ice-sheets, the complication of stratified and unstratified drift may be even greater. While the ice of one epoch is likely to destroy in part the deposits of earlier epochs, it is not likely to obliterate them altogether. In some regions, indeed, the full series of one epoch is buried beneath the deposits of a second, as the soil between shows. In addition therefore to the complicated series of stratified and interstratified deposits of a first epoch, the ice of a second developed a full set of its own. A prolonged series of ice epochs might bring about a most complicated set of relations, the complete unraveling of which would be a most arduous task.

In America the exposed portion of the formation made by the ice-sheet which reached the greatest extension — the Kansan[1] — should possess less complex combinations of stratified drift than the drift of the region further north which was affected by two or more ice-sheets. The drift of the region where the Iowan formation is exposed, should present in vertical section, more alternations of stratified and unstratified drift than the Kansan, but less than the drift of the region where the Wisconsin formation occurs, since the drift of this latter region is the product of at least three ice-sheets.

[1] JOURNAL OF GEOLOGY, Vol. III, p. 270; The Great Ice Age, GEIKIE, p. 753 *et seq.*

CLASSIFICATION ON THE BASIS OF POSITION.

In general the conditions and relations which theoretically should prevail are those which are actually found.

On the basis of position stratified drift deposits may be classified as follows:

1. *Extraglacial deposits,* made by the waters of any glacial epoch if they flowed and deposited beyond the farthest limit of the ice.

2. *Supermorainic deposits* made chiefly during the final retreat of the ice from the locality where they occur, but sometimes by extraglacial streams or lakes of a much later time. Locally too, stratified deposits of an early stage of a glacial epoch, lying on till, may have failed to be buried by the subsequent passage of the ice over them, and so remain at the surface. In origin, supermorainic deposits were for the most part extraglacial (including marginal), so far as the ice-sheet calling them into existence was concerned. Less commonly they were subglacial, and failed to be covered, and less commonly still superglacial.

3. *The submorainic* (*basal*) *deposits* were made chiefly by extraglacial waters in advance of the first ice which affected the region where they occur. They were subsequently overridden by the ice and buried by its deposits. Submorainic deposits, however, may have arisen in other ways. Subglacial waters may have made deposits of stratified drift on surfaces which had been covered by ice, but not by till, and such deposits may have been subsequently buried. The retreat of an ice-sheet may have left rock surfaces free from till covering, on which the marginal waters of the ice may have made deposits of stratified drift. These may have been subsequently covered by till during a readvance of the ice in the same epoch or in a succeeding one. Still again, till left by one ice-sheet may have been exposed to erosion to such an extent as to have been completely worn away before the next ice advance, so that stratified deposits connected

with a second or later advance may have been made on a driftless surface, and subsequently buried.

4. *Intermorainic stratified drift* may have originated at the outset in all the ways in which supermorainic drift may originate. It may have become intermorainic by being buried in any one of the various ways in which the stratified drift may become submorainic.

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